Journal of Engineering and Applied Sciences 8 (2): 69-72, 2013
ISSN: 1816-949X

A Hierarchical Approach for Assigning Examinations to Timeslots and Rooms: A Case Study

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Abstract: An examination timetabling problem at Universiti Kebangsaan Malaysia is a real world problem with additional constraints such as large-enrollment examinations whose number of students is greater than the size of the largest available room which is not considered in the benchmark datasets (e.g., the ITC 2007 datasets). In this research, researchers propose a hierarchical graph colouring heuristic to construct a feasible examination timetable for this practical problem. The heuristic will first schedule the examinations with more constraints such as large enrollment, specific timeslot or rooms. Followed by the examinations with less constraints that will be scheduled into timeslots and rooms by implementing a basic largest degree with large enrollment heuristic and a two-step backtracking procedure. The examinations are assigned to rooms based on room priority. This heuristic will also be tested on benchmark datasets (e.g., the ITC 2007 datasets) to evaluate its effectiveness. Computational results shows that the proposed heuristic is efficient to generate a feasible solution for this practical problem and the benchmark problem.

Key words: Timetabling, heuristic, graph colouring, benchmark, Malaysia

INTRODUCTION

University examination timetabling is a Non-deterministic Polynomial-time (NP) hard problem (Carter, 1986). There are two types of constraints in an Examination Timetabling Problem (ETP): Hard and soft constraints. Hard constraints are prohibited to be violated in order to have a feasible timetable. Whilst the soft constraints are acceptable to be violated but there will be a decrease in quality when generating the timetable. Therefore to generate a high quality timetable, the number of soft constraints violation should be minimized as much as possible without violating any hard constraints.

In the last 2 decades, a significant amount of examination timetabling approaches have been studied such as graph based techniques (Carter *et al*., 1996; Burke and Newall, 2004; Sabar *et al*., 2012); local search based technique such as tabu search (Paquete and Stutzle, 2002) and simulated annealing (Dowsland, 1997); population based algorithms such as ant algorithm (Dowsland and Thompson, 2005) and hyper heuristic approach (Burke *et al*., 2007). Interested readers can refer to Qu *et al*. (2009) for more studies on examination timetabling problems.

The graph based heuristics are the most widely practised approach for solving examination timetabling problem (Carter, 1986). In order to generate a conflict-free timetable using graph based technique, a list of examination is generated according to the decreasing difficulty of scheduling each examination which depend on certain heuristic or criteria. Then, the examinations are scheduled one by one follows according to the order in the generated list. Some of the popular graph based heuristic are:

Largest Degree (LD): The difficulty of scheduling an examination is calculated by the number of conflicts. In this case, the scheduling order is sorted from the most to the least number of conflicts that an examination will encounter.

Largest Enrollment (LE): The difficulty is calculated by the number of students taking an examination. An examination with the large enrollment will have more conflicts such as finding suitable examination rooms. This type of difficulty is known as capacitated examination timetabling problem. In this case, the scheduling order is sorted from the largest to the smallest number of enrollment.

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Largest Weighted Degree (LWD): An examination with largest number of students in conflict are scheduled first. This heuristic is a combination of two heuristics.

Least Saturation Degree (LSD): An examination with the least number of available timeslots is to be scheduled first.

Color Degree (CD): An examination with the most conflicts is to be scheduled first.

The intention of this research is to highlight the important requirements in proposing a heuristic to deal with practical examination timetabling problem. In this study, researchers present a hierarchical graph colouring heuristic to generate a feasible timetable for University Kebangsaan Malaysia (UKM) examination timetabling problem. The proposed heuristic can also be applied on the benchmark datasets.

MATERIALS AND METHODS

Problem statement: The Examination Timetabling Problem for Universiti Kebangsaan Malaysia (UKMETP) is a practical capacitated problem proposed by Ayob. The examinations in UKM can be separated into two subsets: General and law-faculty examinations. The law faculty exams are provided by the faculty of law which takes one and half consecutive timeslot: Morning timeslot plus early half of afternoon timeslot or late half of afternoon timeslot plus evening timeslot. Furthermore, the law faculty examinations should be arranged in the examination rooms that are reserved for the law faculty examinations only. For both set of examinations, some specific requirements are applied. Table 1 lists the special requirements for UKMETP.

The examination in UKM is held in 3 weeks with 5 examination days (Monday to Friday) for each week. From Monday to Thursday, each examination day have 3 timeslots (morning, afternoon and evening) and only 2 timeslots for Friday (morning and evening) due to religious activities. Therefore, there are 42 available timeslots for each semester.

The hard constraints for UKM examination timetabling problem are:

- H_1: All examinations must be scheduled to a single room in a timeslot (except for those with student enrollment greater than the capacity of the largest room)
- H_2: No student can takes two or more examination at a time
- H_3: In all examinations, the total number of students should not exceeds the room capacity
- H_4: No student can take >2 examinations in a day
- H_5: Equivalent examinations are required to be scheduled in the same timeslot and room
- H_6: If a student takes two consecutive examinations in a day, these two exams should be held in the same room
- H_7: Special examination should be isolated from other examinations

Researchers have dropped the constraint related to timeslot capacity, i.e., the total number of students sitting for an examination in each timeslot because it has already being stated in H_3.

Solution approach

Hierarchical approach: The idea of the proposed hierarchical approach is based on the experience of solving UKM examination timetabling problems. For both general and law faculty examinations, the hierarchical heuristic will first separate them into 10 subsets based on the special requirements of each examination and prioritized them based on the level of difficulty in scheduling them (based on experience). The list of subsets and sequence of scheduling for both general and law faculty examinations are listed in Table 2.

For both general and law faculty examinations, the scheduling process starts by scheduling the examination with special requirements (the order is shown in Table 3). Each of these examination subsets is scheduled by applying a hybrid graph colouring heuristics as proposed by Sabar *et al*. (2012). For each iteration, the best timeslots and well-fitted room will be assigned to the examinations that need to be scheduled first. The examinations to be scheduled are sorted based on the priority as shown in Table 3 and then based on the difficulty index as determined by hybrid graph colouring as in Sabar *et al*. (2012).

Table 1: List of special requirements for UKMETP dataset

Special requirements	Description
Equivalent exams	Exams to be scheduled at the same time and room
Special room requested	Exams required to be arranged in specified room (s)
Special timeslot requested	Exams required to be scheduled in specified timeslots (s)
Huge enrolled exams	Number of student sitting for the exam exceeds the capacity of the largest available room

Table 2: Subsets of exams and sequence of scheduling

Priority/sequence of scheduling	Subset of exams
1st	STR+LE
2nd	STR+SRR+EE
3rd	STR+SRR
4th	STR+EE
5th	STR
6th	LE
7th	SRR+EE
8th	SRR
9th	EE
10th	General

EE = Equivalent Exams; SRR = Special Room Requested; STR = Special Timeslot Requested; LE = Huge enrolled exams; General = A group of exams that has no special requirement

Two-step backtracking mechanism: The two-step backtracking mechanism is proposed to modify the timetabling generated in previous iteration when an examination failed to be arranged accordingly. At the beginning of the first and second backtracking procedure for both examinations, a list of timeslot is generated by non-decreasing order. Any examinations that conflicted with unscheduled examinations in each timeslot are to be rearranged. The unscheduled examinations refers to any examinations that failed to be scheduled sequentially in an attempt to identify a feasible or best timeslot. For each iteration of the first procedure, any examinations that conflicted with the unscheduled examinations will either be moved from selected timeslot into other timeslot or by swapping them with clash free examinations found in other timeslot.

The second procedure is executed only after the first backtrack procedure failed to schedule the unscheduled examinations. The difference between the second and the first backtracking process is that it will go through all the timeslots. For each timeslot, the process will try to unscheduled the examinations that conflicted with the unscheduled examinations. This procedure will be employed when the process moving, swapping or rearranging the examinations failed. After going through all timeslots, the timeslot with the lowest sum of weighted degree will be selected to arrange the unscheduled examinations. Figure 1 shows the flow chart of the hierarchical approach.

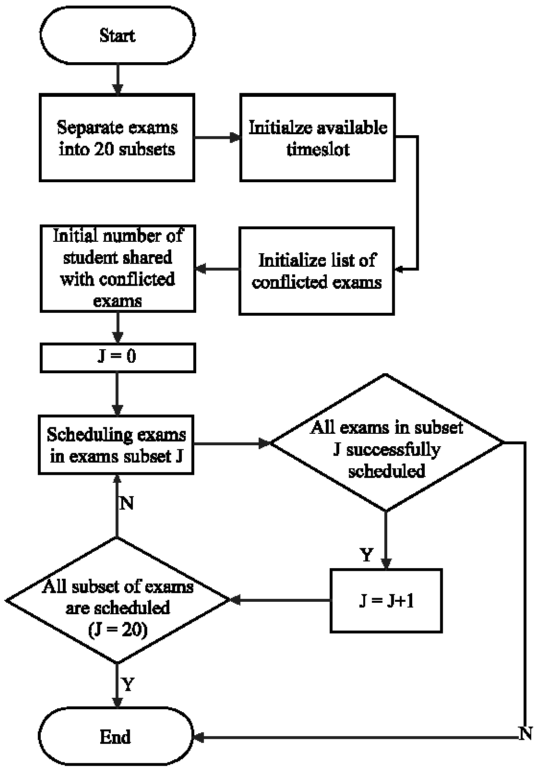

Fig. 1: The flow chart of hierarchical approach (without back tracking)

Table 3: Characteristics of modified UKM11-2 dataset

Entity	Characteristics
General exams	833
Law faculty exams	27.0
Exams with special request	134
Timeslots	26.0
Days	9.00
General room	3.00
Law faculty room	1.000
Students	43210
Total number of seats	1930
Confliction index	0.020

RESULTS AND DISCUSSION

The evaluation of the proposed approach will be carried out on two datasets: UKM examination timetabling dataset and ITC 2007 examination timetabling benchmark dataset. The algorithm is programmed by Java programming language and running on a 64 bit Windows 7 PC with an Intel i5 3.3 GHz CPU and 8 GB RAM.

To evaluate the performance of the proposed algorithm, the experiment is carried out on a modified version of UKM11-2 dataset which is more difficult to solve than the original one. The modification is to remove some of the timeslots that did not have specified time requirement from the original dataset. Table 3 shows its characteristics whilst Table 4 shows the description of ITC 2007 examination timetabling problem datasets.

Table 5 presents the percentage of success (between 0 and 1) in finding a feasible solution from each 30 runs test with 200-600 ns of time consumption for each run depending on the heuristic. Based on the result obtained, the comparison between test 1-3 and 4-6 infers that the hierarchical approach could offer a higher possibility of

Table 4: Description of ITC 2007 examination timetabling problem datasets

Instances	Conflict index	Exams	Exams with special request	Students	Rooms	Timeslots	Period hard constraints	Room hard constraints
Exam 1	5.05	607	21	7891	54	7	12	0
Exam 2	1.17	870	16	12743	40	49	12	2
Exam 3	2.62	934	203	16439	36	48	170	15
Exam 4	15.00	273	17	5045	21	1	40	0
Exam 5	0.87	1018	90	9253	42	3	27	0
Exam 6	6.16	242	50	7909	16	8	23	0
Exam 7	1.93	1096	38	14676	80	15	28	0
Exam 8	4.55	598	35	7718	80	8	20	1

Table 5: Result on modified UKM11-2 dataset

Tests	Heuristic	Possibility of find feasible solution (%)
1	Non-hierarchical no-backtrack LD	0
2	Non-hierarchical no-backtrack LE	0
3	Non-hierarchical no-backtrack SD	0
4	Hierarchical no-back-trace LD	23
5	Hierarchical no-back-trace LE	0
6	Hierarchical no-back-trace SD	0
7	Hierarchical back-trace LD	80
8	Hierarchical back-trace LE	78
9	Hierarchical back-trace SD	0

Table 6: Result on ITC 2007 datasets on possibility of generating feasible solutions (%)

Test	Strategies	Exam 1	Exam 2	Exam 3	Exam 4	Exam 5	Exam 6	Exam 7	Exam 8
1	Non-hierarchical no-backtrack LD	0	0	100	0	0	0	0	0
2	Non-hierarchical no-backtrack LE	0	0	100	0	0	23	23	0
3	Non-hierarchical no-backtrack SD	0	0	100	0	0	0	23	0
4	Hierarchical no-back-trace LD	73	93	100	0	93	50	97	90
5	Hierarchical no-back-trace LE	80	87	100	0	87	3	90	90
6	Hierarchical no-back-trace SD	76	93	100	0	90	0	83	90
7	Hierarchical back-trace LD	100	97	100	100	97	83	97	100
8	Hierarchical back-trace LE	100	93	100	17	87	90	90	100
9	Hierarchical back-trace SD	100	97	100	0	83	83	90	97

constructing a feasible solution. The comparison between test 4-6 and 7-9 indicates that the proposed two-step backtracking mechanism increases the performance of hierarchical approach.

Table 6 lists the experimental result for eight ITC 2007 examination timetabling problem datasets. The possibility (0-1) of obtaining feasible solution from 30 runs for each dataset and heuristic, spends 90-1.3 msec depending on the dataset and heuristic. It shows that the hierarchical approach with backtrack mechanism and Largest Degree (LD) heuristic achieves the most feasibility compared to other basic heuristics.

CONCLUSION

In this research, researchers proposed a hierarchical heuristic to generate feasible timetables for Universiti Kebangsaan Malaysia examination timetabling problem. In addition, a two-step backtracking procedure was implemented to rectify the infeasible timetable. The experimental result indicates that the proposed method is efficient to generate a feasible solution for both UKM timetabling problem and benchmark datasets.

ACKNOWLEDGEMENT

The researchers wish to thank Ministry of Higher Education for supporting this research under the FRGS Research Grant Scheme (FRGS/1/2012/SG05/UKM/02/11).

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